Sloshing and Scaling: Experimental Study in a Wave Canal at Two Different Scales

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ABSTRACT

Sloshing model tests are the basis of any sloshing assessment for a new membrane LNG carrier project. The statistical pressure results have to be scaled to full scale in order to derive design loads. The approach for scaling is not obvious as multi-physics occur within the impacts.

Experimental modeling is based on the Froude scaling assumption: if the forced motions at small scale are defined with a geometrical scale \(1/\lambda\) and a time scale \(1/\sqrt{\lambda}\), the velocities in both fluids, liquid and gas, should be in Froude accordance at both scales. This is exact for the global flow but Braeunig et al., (2009) have shown that it is wrong locally during the sloshing impacts, even though the density ratio between the fluids are kept the same at both scales, because the speeds of sound in the model liquid and gas are not in Froude accordance with the speeds of sound of respectively LNG and natural gas. The study presented here is an experimental attempt to show evidence of this so-called compressibility bias of sloshing experimental modeling.

Performing sloshing tests with model tanks at two different scales would have led only to a statistical comparison of the impact pressures. In order to have a direct deterministic comparison of Froude-similar liquid impacts on a wall at two different scales, the study deals with single breaking waves in a laboratory wave canal at two different scales referred to as scales \(s_1\) and \(s_{1/2}\).

After describing the experimental set-up and the breaking wave generation process, the paper shows the difficulties to reproduce accurately local developments of the impacts and the significant consequences of light discrepancies on the pressures. At the end the study describes how a relatively good similarity between flows at the two scales is obtained. A global analysis shows the general trend of the scaling for the pressures inside gas pockets.

KEY WORDS: Sloshing, Liquid Impact, Breaking Waves, Flume tank, Experiments, scaling, Froude, Compressibility, LNG carriers

INTRODUCTION

Repeating sloshing model tests leads to a large scattering of the impact pressures in the sample. Only after a statistical post-processing of long duration tests, allowing for a large sample, will the pressure results become reasonably repeatable. The origin of the scattering of impact pressure is commonly attributed to local phenomena while the global flow is considered as quasi-deterministically defined. The scattering which is also a lack of repeatability can be attributed to the complex turbulent and three-dimensional flows. It makes sense that studying a single two-dimensional breaking wave should lead to a better repeatability. Reproducing two flows at two different geometrical scales consists in imposing Froude-scaled excitations to a liquid. According to waves equations the global flow (velocities) remains the same after Froude-scaling. What happens locally around each impact area (the local flow), during a very short duration starting with the compression of the escaping gas, is more complex and involves multi-physics including gas compressibility effects. For realistic impacts, the physics local phenomena should occur with the same intensity at both scales. The transfer of momentum between gas and liquid is one of the phenomena and is governed by the ratio of densities between gas and liquid. Keeping the same density ratio at both scales takes off a bias source between the scales. Thus, it allows for the studying of other sources of differences. The principle remaining source of bias is then compressibility effects. Other sources could be mentioned such as phase transition or different hydro-elastic effects.

The objective of the study presented in this paper is to compare deterministically local fluid impact pressures obtained experimentally at two different scales for similar Froude-scaled global flows. This objective leads directly to different pre-requirements:

1. Ensure that, at each scale, the global flow is repeatable when repeating carefully the same wave maker signal
2. Ensure that, at each scale, local impact pressure measurements are repeatable when repeating carefully the same global flow
3. Ensure that the experimental set-up allows a good similarity of the global flows at the two scales for the different conditions studied

The paper explains which precautions are necessary to achieve these requirements.

The experimental facility selected is the ~17 m laboratory flume tank of Ecole Centrale Marseille (Kimmoun et al., 2009). A flap-type wave maker generates idealized, unidirectional breaking waves by a focusing process. The waves focus at a selected distance of the flap and impact an instrumented rigid wall when breaking.

TEST SET-UP AND BREAKING WAVE GENERATION

Two scales are studied with a geometrical ratio of \(\frac{1}{2}\) in all directions. They are referred to as scale \(s_1\) and \(s_{1/2}\). Thanks to a movable test wall, the set-up is adapted for dealing with the two scales. At both scales, the distances between the wave maker and the wall, the liquid heights in the canal, the locations of the pressure sensors with regards to the free surface at rest are geometrically scaled and the wave maker signals are...